COOLING THE EXHAUST AIR

10 MINUTE READ

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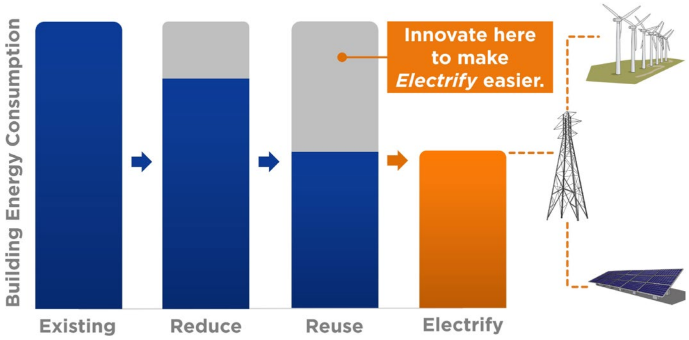
Abstract

Decarbonization of the built environment remains a formidable challenge. To solve this challenge, two crucial events must transpire: a phased transition of the electric grid to renewables and conversion of a building's fossil fuel use to electricity. While many building end uses are electric, such as lighting and plug loads, a large share of energy remains unconverted: heating. The electrification of heating systems is a critical step toward achieving a building's low-carbon goals. However, implementing electric heating solutions, especially in colder regions, comes with its share of obstacles. Heat pumps have emerged as the go-to solution to electrify heating by effectively transferring heat from the ground or outside air without relying on onsite heat generation. Yet, in densely populated areas, limited space constrains both air- and ground-source heat pump options. In this article, we discuss how to address this challenge by moving beyond the traditional recovery of waste energy from exhaust air typically performed by energy recovery ventilators (ERVs). Instead, we explore the concept of actively cooling the exhaust air as a means of extracting additional heat, which can supplement heating demands and reduce the capacity required for new electric heating equipment in tall commercial buildings.

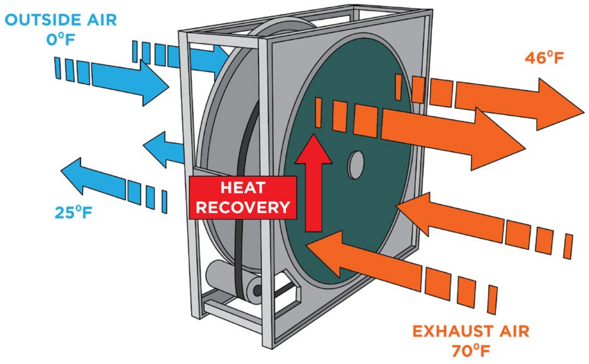
Introduction

In the pursuit of building decarbonization, the concept of reuse takes center stage in the electrification strategy.

The status quo solution is to reduce energy and hope it translates to reduced carbon emissions. However, innovation needs to happen in the energy recovery space that will make future electrification more cost-effective and space-efficient without overly stressing the electric grid.



By focusing on energy recovery and repurposing waste, engineers are finding innovative ways to optimize efficiency and minimize environmental impact. Traditional energy recovery methods, such as air handling units with rotary wheels, flat plate heat exchangers, or wrap-around coils, for example, are time-tested and proven solutions that reduce the conditioning needs of ventilation air. However, these systems have limitations. The heat exchange is not ideal, and the supply approach temperature is constrained by the exhaust air temperature. While these systems require minimal input energy, their energy-saving impact is modest. Additionally, the requirement for colocating intake and outtake air streams poses physical challenges, particularly in existing buildings where ventilation and exhaust designs are often treated as separate systems.

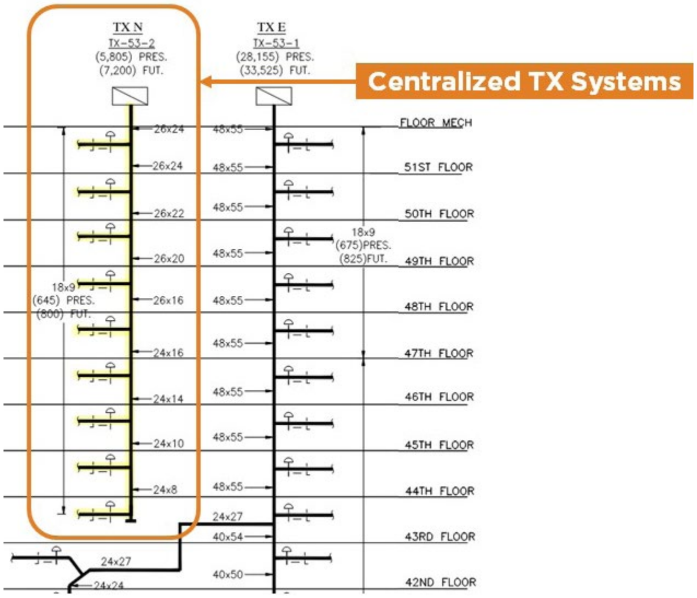


Despite its imperfections and implementation challenges, recovering every BTU (unit of energy) leaving the building is necessary to offset building heating and cooling loads before electrification. There are many sources of heat in a building that should be assessed for their heat recovery potential. Even uncommon sources such as cooling tower water, general exhaust air, kitchen exhaust air, toilet exhaust air, and air exfiltration are viable candidates.

Recovering Heat from an Unusual Source: Toilet Exhaust

We are going to focus on the untapped potential of heat recovery from toilet exhaust (TX) in buildings. While many engineers overlook this source of heat due to mechanical codes, separate system requirements, and the perceived "ick!" factor of toilet exhaust, this source holds significant value as a scalable candidate for heat recovery and even additional heat extraction with the implementation of a heat pump (more on that later).

Typically, toilet exhaust systems in high-rise commercial buildings operate as stand-alone systems with dedicated fans and ductwork, adhering to specific design and discharge regulations. These systems maintain a constant volume flow and air temperature year-round, usually between 70 - 75°F, or that of the internal occupied set point temperature. As a result, TX systems consistently provide a readily available source of heat that often congregates in a centralized location, making it an attractive option for recovery initiatives in existing buildings.

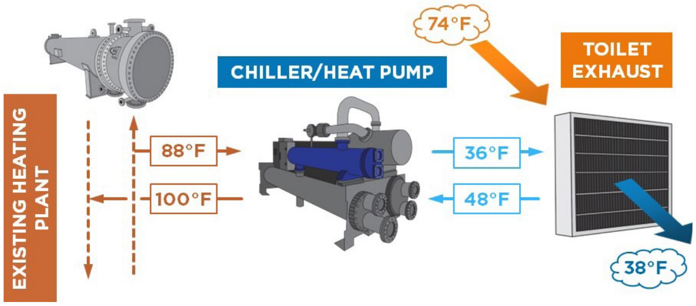


Why Not Cool the Exhaust Air?

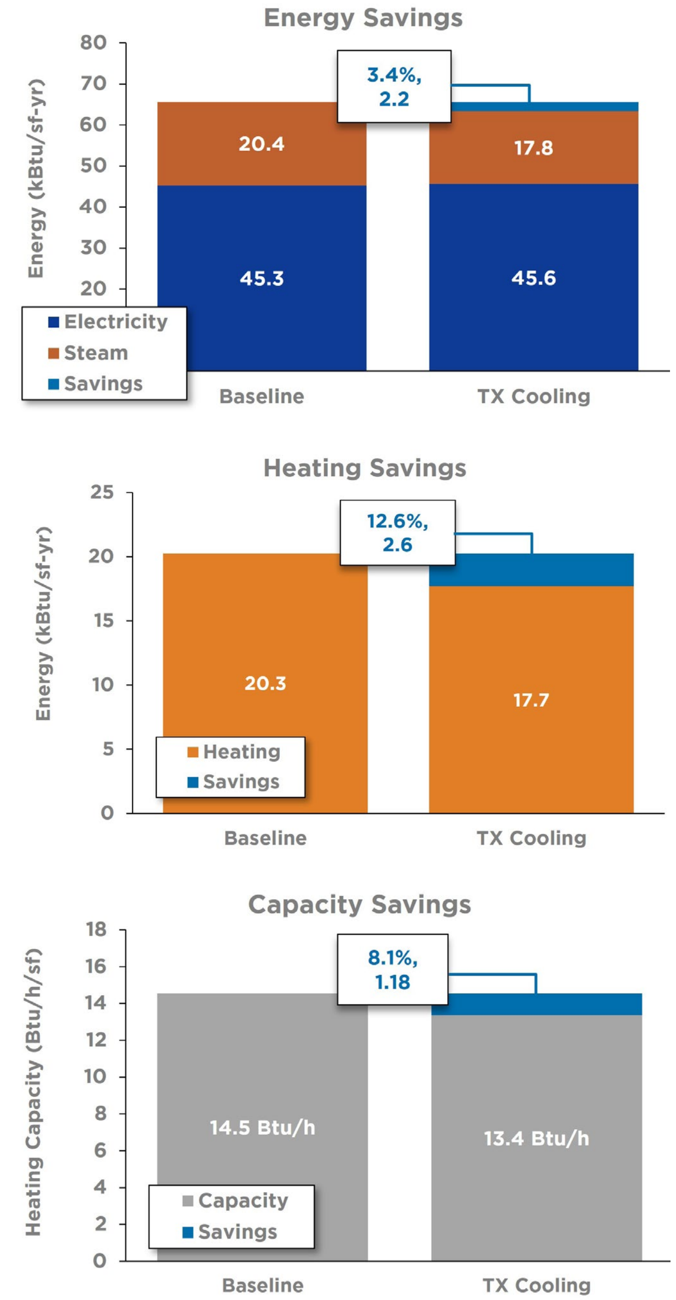
To harvest the heat from the TX system and use it elsewhere in the building, engineers can employ typical heat recovery methods discussed earlier in this article or they can go a step further and actively cool the exhaust air with a heat pump.

By installing a cooling coil(s) within the toilet exhaust air stream, the entering air (already at 75°F) is cooled down to a lower temperature (i.e., 55°F) using the cooling coil's internal fluid. The coil absorbs heat from the air, causing the fluid (usually chilled water) temperature leaving the coil to rise. This warmed water is then circulated to a heat pump, where the refrigeration cycle cools it back down to its original set point temperature. The heat pump's refrigeration process creates a temperature lift from that of the evaporator to the condenser, creating hot condenser water (100+ °F) that can then be used to supplement the building's hot water system. In buildings that have low-temperature hot water systems or secondary hot water loops with supply temperatures ranging between 90°F - 130°F, this heat pump's condenser water can be directly fed into the hot water plant, reducing the need for more boiler or steam heating energy.

A simplified diagram of the heat pump in action and associated fluid loops and their temperatures is shown below:



Want more heat? To optimize heat recovery in the exhaust air heat pump system, the toilet exhaust air can be cooled to very low temperatures, such as 38 or 36°F. Since the discharge air is not utilized for any practical purposes and is not exposed to humans, these lower temperatures can be achieved. However, it is crucial to maintain the discharge air temperature above 32°F to prevent ice or frost formation, which can damage the heat exchange coil and impede airflow. To achieve these colder temperatures, a glycol-based working fluid is used for cooling instead of pure water. It is important to note that using glycol reduces the heat transfer capabilities and efficiency of the heat pump, requiring additional input energy to achieve the desired heat recovery and generate sufficiently warm condenser water. Despite these considerations, the additional benefits of supercooling the toilet exhaust air outweigh these limitations. Finally, the input energy (electricity) to operate the heat pump adds to the heating effect and increases the amount of heat delivered to the building's heating system.

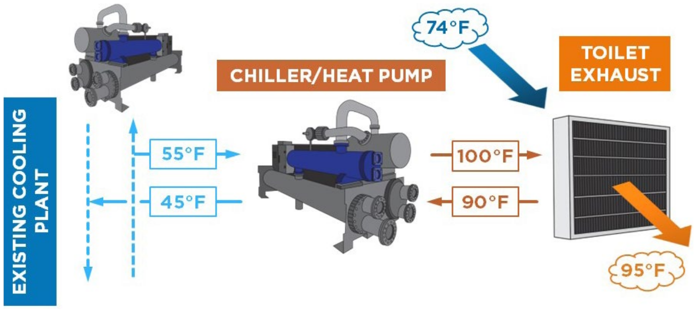


Case study for a 1.1 million sq.ft. commercial office in New York City. Results show a 2.5M kBTU energy savings (3.4%), a 2,355 Mlb heating steam savings (13%), and a 1,300 MBH heating load reduction (8%).

Does This Work in Reverse for Summer?

To expand the functionality of the system, the heat pump can operate in reverse during the summer, acting as a chiller. By switching the refrigerant flow direction using a reversing valve, the heat exchangers swap roles: the evaporator becomes the condenser, and the condenser becomes the evaporator. In this mode, the toilet exhaust acts as a heat sink, raising its temperature from around 75°F to potentially 85 - 90°F.

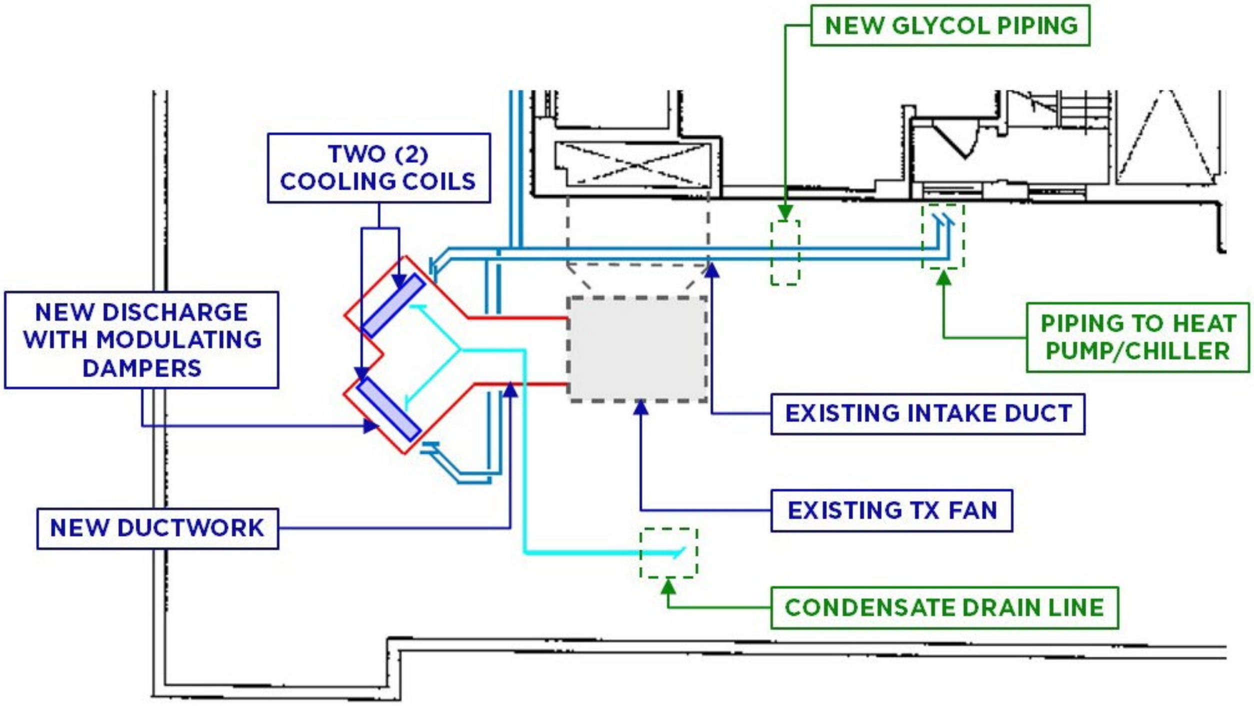
The condenser water from the exhaust air chiller flows to the toilet exhaust stream via the existing heat exchange coil (now a heating coil), releasing heat to the toilet exhaust. The cooled condenser water is then returned to the chiller and the cycle continues. On the evaporator side, supplementary chilled water ranging from 45 - 55°F can be distributed to the building's existing chilled water system. This set-up can be more efficient than using a cooling tower to reject heat to the warmer outdoor air, as the toilet exhaust air is cooler in comparison, typically around 95°F versus 75°F.



However, it is important to assess the efficiency of this dry-cooled chiller system in comparison to the building's existing water-cooled chiller plant. Depending on factors such as the capacity of the current chiller and cooling tower set-up, adding the reversing valve functionality may not be cost-effective. Conducting an engineered analysis is essential to determine the potential benefits of using the TX exhaust air heat pump for cooling in the summer. In many cases, prioritizing heat recovery during winter proves to be the most impactful option, while augmenting cooling for summer may not yield significant advantages.

Design Considerations

Design considerations are vital for the successful implementation of this enhanced heat recovery strategy.



Manufacturers offer a range of equipment options, such as water-to-water heat pumps, reverse-cycle heat pumps, or chillers suitable for this application. Other heat pump styles like VRF (variable refrigerant flow) heat pumps or DX devices are also good candidates.

Sizing the system depends on the available toilet exhaust airflow, measured in cfm, while physical space allocation and proper piping design are essential. Cooling coil selection, condensate management, and electrical capacity evaluation are crucial factors to address as well. Consulting an engineering professional helps assess the building's layout and feasibility for a heat recovery strategy tailored to its specific requirements.

Conclusion

In summary, using heat pump technology to actively cool or heat toilet exhaust as a means of enhanced heat recovery is an innovative yet viable approach to supplement heating and cooling, thereby reducing the capacity needed for new electric equipment in buildings.

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